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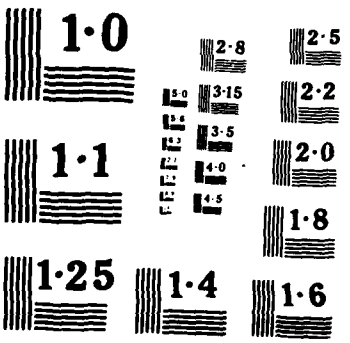
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The research performed under this grant falls under three general categories:

1) Circuit-switched routing in non-hierarchical networks,
2) Voice in integrated networks,
3) Decentralized optimal flow control.

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ROUTING AND FLOW CONTROL

IN

VERY LARGE COMMUNICATION NETWORKS

Final Report

Thomas E. Stern

June 13, 1986

U. S. Army Research Office

Grant No. DAAG 29-83-K-0021

Columbia University

New York, New York 10027

Summary of Research

The research performed under this grant falls under three general categories:

1. Circuit-switched routing in non-hierarchical networks
2. Voice in integrated networks
3. Decentralized optimal flow control

A summary of each of these efforts follows.

1. Circuit-switched routing in non-hierarchical networks

As demand for telecommunications services of all types (voice, data, video, etc.) continues to grow, it becomes more and more important to utilize the capacity of existing equipment as efficiently as possible. In our currently installed telephone plant, for example, the capacities of switches, transmission lines and other equipment are limiting factors in determining the quality and quantity of the many different services that these networks provide. It is therefore of particular importance to utilize this equipment as efficiently as possible. One significant factor affecting the efficiency of telecommunication networks is the manner in which traffic is routed through the network. Until recently, networks were structured in a hierarchical form wherein each switching center in the network was assigned to a particular level in the hierarchy. Strategies for routing calls through networks of this type were fairly simple, attempting to find available paths through the lower levels of the hierarchy, and then working upward until an available path was found, with the call attempt being blocked if all alternate paths were busy. With the advent of highly sophisticated, computer-based switches, it is possible to design networks in a more complex non-hierarchical form, and at the same time develop more elaborate routing strategies adapted to these

forms, which improve the efficiency of network utilization. Our work deals with these "non-hierarchical" routing strategies. We have developed techniques for routing traffic in circuit switched networks (these are the traditional types of networks providing voice service), and combined circuit- and packet-switched networks, used for providing integrated services (i.e., mixtures of voice, data, and other services).

In the first part of the work, a number of routing schemes have been compared on the basis of grade of service, (measured by percentage of blocked calls) and complexity of implementation. It has been well-established in the literature that alternate routing strategies, in which call attempts are made in order, over a series of alternate paths, if a direct access (first try) path is not available, provide blocking performance improvement in the case of lightly-loaded traffic. They may become unstable, however, for heavy traffic. Control strategies are thus needed. Trunk reservation for direct access traffic has been suggested. We have compared other, load-dependent control strategies with trunk reservation, as well as with a control scheme combining aspects of load-dependent control and trunk reservation. It is possible to obtain good blocking performance with reduced cost of implementation by going to a combined strategy.

In another part of the work, a performance study has been carried out of combined packet-switched data and circuit-switched voice using non-hierarchical routing. The tradeoff between voice performance and data performance (time delay) has been studied for the various types of non-hierarchical routing strategies noted above.

We expect that the results of this work will be of value in modern telecommunication network design and control. By exploiting the intelligence which it is now possible to build into network hardware, the routing techniques we have studied are able to improve the overall efficiency, reliability and survivability of these networks. Work is continuing on this area focusing on the combined routing of circuit-switched (voice) and packet-switched (data) traffic.

2. Voice in Integrated Networks

The goal of this research is to determine appropriate means of combining voice with other services for transmission over a common integrated network. Our studies have been focused on packet-switched architectures. While realtime traffic (voice and video) has traditionally been transmitted in a circuit-switched mode, many arguments can be made in favor of all-packet-switched network architectures for integrated services. These range from the economies of sharing common hardware, software, and transmission facilities to the vast potential for new services involving such concepts as voice-computer interaction.

Transmission of voice in packetized form offers great flexibility in trading off performance objectives against costs. For example, required transmission capacity can be reduced in a packet-switched system at the expense of increased delays, higher percentages of lost packets, reduced voice quality, etc.

Work on packet voice has continued throughout this grant. The problem of transmitting packet voice throughout an integrated services digital network

was treated from several points of view. First, a model of a concentrator on a single link was developed and analyzed producing information on tradeoffs between network delay, packet loss and network loading. Second, these results were extended to the local area network environment, wherein the effect of the network access protocol was studied. In a third analytical study, the work was extended to a combined voice/data multiplexor.

An experimental effort is also underway using equipment acquired under our recent DoD equipment grant. In the experimental work we are attempting to develop an integrated workstation, which handles voice, data and other traffic. The initial work involves the modification of two types of intelligent workstations (SUN and MASSCOMP) to process voice in real time. More recently we have begun to study the performance of packet voice systems in which embedded coding is used, resulting in two or more streams of encoded information defining the voice waveform. The more significant information is carried in high priority packets and the less significant information in low priority ones. In such systems, the higher queuing delays (with eventual lost packets due to overly long delays) will occur for the lower priority packets, with the more significant part of the information experiencing improvement in performance over what it would have had without priorities. Furthermore, if network nodes are allowed to drop low priority packets in the face of network congestion, overall network performance can be improved at the cost of some loss in voice quality. Basically, the priorities act to dynamically vary the voice quality in the face of rapidly fluctuating network load. We have developed a queuing model for a single link of this type of system. Both arrival rate and service rate are governed by a birth-death process, and buffer size is assumed infinite. By solving a set of differential

equations, the equilibrium queue length distributions and waiting times were found.

Based on the performance evaluation studies described above, we have begun work on implementation of an integrated workstation (IWS) in which data and graphics capabilities are augmented by voice (and eventually video) services. The IWS under study will be capable of serving as an interface between a telephone and a local area network (LAN) so as to provide ordinary as well as enhanced voice services over the LAN. In addition, it will be used to explore new services which involve voice in combination with other media, including computer data, graphics, and video. An implementation is under study, based on a SUN workstation. The telephone controller is based on a single board computer which does speech activity detection, packetization, voice reconstruction and various control and supervisory functions. The computer interfaces both to the Sun workstation and to our own LAN testbed (MAGNET).

3. Decentralized Optimal Flow Control

The problem of network and user flow control arising in local area networks and time sharing computer systems has been defined and investigated. A multiclass queuing system with two classes of users serves as a model for which optimal flow control strategies are to be derived. The first class models the interfering traffic while the second class models the traffic generated by a new user logging onto the network. Decentralized optimal flow control strategies are obtained that maximize the network (respectively user) average throughput subject to a bounded average network (respectively user) time delay constraint. These strategies use partial observations: only

the number of the second class of packets is available for controlling the packet flow. Two structural results are presented. The first is a representation theorem, which shows that the conditional arrival rate estimate is a sufficient statistic for the network optimization problem. The second result, referred to as the separation principle, provides a solution to the user optimization problem via the conditional departure rate estimate. By constructing the equivalent arrival and departure processes, it is shown that the Norton equivalent is simply the conditional estimate of the arrival and departure rates. Under both optimization criteria, the resulting optimal control is shown to be a window-type flow control mechanism (bang-bang control). The window size L is a function of the maximum tolerated time delay T, the input capacity c, the service rate u and the interfering packet flow . It is also shown that the optimal window size under the network criterion is smaller than or equal to that under the user criterion.

Degress Awarded

S. Gauguly Ph.D.

M. Luhanga Ph.D.

T-K Yum Ph.D.

T. Hsiao Ph.D. (August 1986)

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Papers presented or submitted for publication

Thomas E. Stern, "A Queuing Analysis Of Packet Voice," Globecom'83, November 1983, San Diego, California.

Thomas E. Stern and Amalie J. Frank, "Onboard Demand Scheduling Of a SS/TDMA Multibeam Satellite With Integrated Circuit - And Packet-Switching," Annual Digital Satellite Comm. Conf., 1984, Phoenix, Arizona.

Mischa Schwartz, "Modeling and Queuing Analysis in Communication Networks," presented, Globecom'83, San Diego, Dec. 1983.

Aurel A. Lazar & T. Robertazzi, "On the Application of Linear Programming to Optimal flow Control," Proceedings of the Twenty First Annual Allerton Conference on Communication, Control and Computing, University of Illinois, Urbana, October 5-7, 1983.

Aurel A. Lazar & J. Coyle, "Optimal Flow Control in a CSMA/CD Environment," Proceedings of the Twenty First Annual Allerton Conference on Communication, Control and Computing, University of Illinois, Urbana, October 5-7, 1983.

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END

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